CLOUD MICROPHYSICAL PROPERTIES DERIVED FROM GEOSTATIONARY SATELLITE DATA

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ABSTRACT

Cloud microphysical properties are a key factor for determining the effect of clouds on radiation in the atmosphere and the relationship between the hydrological cycle and the radiation budget. Recent advances in geostationary satellite sensors now permit us to derive cloud optical depth, phase, and particle size from multispectral imagers over the complete diurnal cycle. This capability will allow us to better monitor and understand the dynamics of cloud formation and dissipation as well as the impact of clouds on the radiation budget. This paper presents the results of applying a multispectral microphysical retrieval algorithm developed for the Clouds and Earth's Radiant Energy System (CERES) project to GOES-8 data over the USA and the Pacific Ocean. This procedure has been used successfully to produce real-time cloud properties on a continuous basis during field missions and over validation sites. An advanced version of this algorithm is being developed for application to the MSG SEVIRI using the additional channels (e.g., 1.6 µm) that SEVIRI will provide. The methodology and examples of the output products from this new application are presented.

1. INTRODUCTION

The Clouds and Earth's Radiant Energy System (CERES; *Wielicki et al.* 1998) is designed to measure the global radiation budget at a gridded resolution of 1° x 1° using broadband scanning radiometers on up to three satellites in polar or mid-inclined orbits. Since cloud macro- and microphysical properties are key factors for determining the effect of clouds on radiation in the atmosphere and the relationship between the atmospheric hydrological cycle and the radiation budget, CERES also derives cloud properties from high-resolution multispectral imagers aboard the same spacecraft. This combination of cloud properties and broadband radiative fluxes should provide the most accurate dataset to date for monitoring the global radiation budget and for constraining General Circulation Model (GCM) climate calculations. However CERES cannot capture continuous variations in clouds and radiation: this can only be done using geostationary data.

Recent advances in geostationary satellite sensors now permit the derivation of cloud optical depth, phase, and particle size and the determination of surface emittance, temperature, and spectral albedo over the complete diurnal cycle. The CERES retrieval algorithms and surface property maps have been adapted to analyze Geostationary Operational Environmental Satellite (GOES-8) data in nearly operational, continuous basis. The high temporal resolution of geostationary data allows these cloud products to be used in conjunction with scientific field missions and other applications that require real-time information.

The Geostationary Earth Radiation Budget (GERB) and the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) on the upcoming Meteosat Second Generation (MSG) will enable the combination of radiation budget and cloud properties together at high spatial and temporal resolutions.

2. CERES CLOUD RETRIEVAL ALGORITHM

CERES instruments are currently operational aboard two satellites, the 35° inclination orbiting TRMM and the sun-synchronous Terra. CERES will also fly aboard the sun-synchronous Aqua satellite that is scheduled to be launched in December 2000. Cloud properties are derived using data from the Visible Infrared Scanner (VIRS) on TRMM and the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard Terra and Aqua. A set of algorithms has been developed to derive cloud height, optical depth, phase, effective particle size, and water path for each pixel *(Minnis et al.* 1995; 1998a, 1999 and *Arduini et al.* 1999). Daytime retrievals use the 0.65, 3.75, and 10.8 µm channels for microphysical retrievals. The 1.6 and 12.0 µm channels are used to augment the cloud mask and for water phase determination. Nighttime microphysical retrievals using the 3.75, 10.8, and 12.0 µm channels are used to derive microphysical properties for optically thin (optical depth < 6) clouds.

Accurate global maps of clear-sky surface properties are crucial to the cloud retrievals. Surface emissivity is necessary for determining skin temperature and the energy exchange between the surface and the atmosphere. The skin temperature and emissivities and albedos for the relevant channels are needed for the cloud mask and to define the background radiances. Currently, the CERES cloud algorithms use monthly maps of 0.65 and 1.6 µm clear-sky albedo (*Sun-Mack et al.* 1999) and 3.7, 10.8, and 12-µm emissivities (*Smith et al.* 1999) derived from AVHRR and VIRS data. These maps are updated whenever clear sky observations are made in order to track weekly-to-monthly scale variability in the surface properties.

3. IMAGER CALIBRATION

To perform multi-satellite studies, it is first necessary to intercalibrate the relevant channels on each instrument. Currently, we normalize the visible (0.65 µm), infrared window (10.8 µm), split window (12 µm), and solar infrared (3.7 µm) channels on various satellites to their counterparts on the NOAA-14 Advanced Very High Resolution Radiometer (AVHRR) using the technique of *Nguyen et al.* (1999). These other satellites include the GOES imager, the VIRS on TRMM, and the Along track Scanning Radiometer (ATSR-2) on ERS-2. The latter two instruments include a near-infrared (NIR; 1.6 µm) channel. Currently the 1.6 µm channel on VIRS is being normalized to the ATSR-2 using the viewing geometry matching procedure of *Nguyen et al.* (1999).

Monitoring of the GOES East and West satellites since 1994 has produced a clear definition of the gain degradations in their VIS channels. We will perform similar calibrations using the SEVIRI channels that best match the spectral bands on AVHRR, GOES, VIRS, MODIS, AVHRR, and EPIC. MODIS is a multispectral imager on the sun-synchronous Terra and Aqua satellites, while the EPIC is an 8-km resolution UV, VIS, and NIR imager on the Triana satellite, which will be in an L1 orbit. Images of the sunlit Earth will be taken every hour by EPIC. We will cross-calibrate all relevant channels on the subject instruments every 1 to 3 months.

3. VALIDATION OF CLOUD RETRIEVALS

The validation of cloud properties derived for CERES is ongoing. The initial results from the CERES analysis of VIRS are, in general, consistent with previous retrievals of cloud properties from satellite measurements and the current understanding of the diurnal cycles of clouds. More detailed validation has begun using in situ and surface-based cloud observations. Initial validation results (*Young et al.* 1998; *Mace et al.* 1998) show that the CERES ice-cloud property retrievals are in good agreement with in situ and radar-derived values of D_e, and ice water path *IWP*. A comparison of VIRS stratus cloud retrievals over the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site in Oklahoma with surface-based measurements (*Dong et al.* 1998) has shown agreement of water droplet radius to within 8%, and liquid water path to within 11%.

Surface/satellite comparisons are often difficult due to the different temporal and spatial scales of the measurements. The validation analyses above have relied on using cases with spatially uniform clouds. Since the occurrence of such clouds is limited and not necessarily concurrent with CERES satellite overpasses, the results of these studies are based on a small number of cases. By adapting the CERES cloud algorithm for use with data from geostationary satellites, the number of cases that can be used to validate the satellite-based retrievals will be increased dramatically.

4. APPLICATION OF RETRIEVALS TO GEOSTATIONARY DATA

Starting in March 2000, the CERES cloud retrieval algorithm has been used to continuously process GOES-8 data over a 14° longitude by 10° latitude region centered over the ARM SGP site. This site was chosen since it is one of the primary validation sites used by CERES. In addition, ARM staged an intensive operation period during February and March for which these products were provided in near real time.

Examples of the cloud products are shown in Figures 1 and 2. The four panels of Figure 1 show the results of the cloud mask and phase identification for four consecutive 1-hourly images from 15:45 to 18:45 UT on 3 March 2000. A slow-moving rotating storm system moved through the area during this time. The retrieved cloud mask shows excellent temporal consistency throughout the time period as the solar geometry changes. Figure 2 shows the retrieved water droplet radius for the pixels identified as water phase. Once again, the results show strong temporal consistency with most retrieved radii between 6 – 16 μm. Larger droplets are seen near the ice cloud suggesting some cirrus contamination in the retrievals. The retrieval has identified many of the pixels in the scene as containing supercooled water. This suggests that this procedure can potentially be used for monitoring aircraft icing conditions. Images and animated loops of the satellite imagery, cloud properties, and

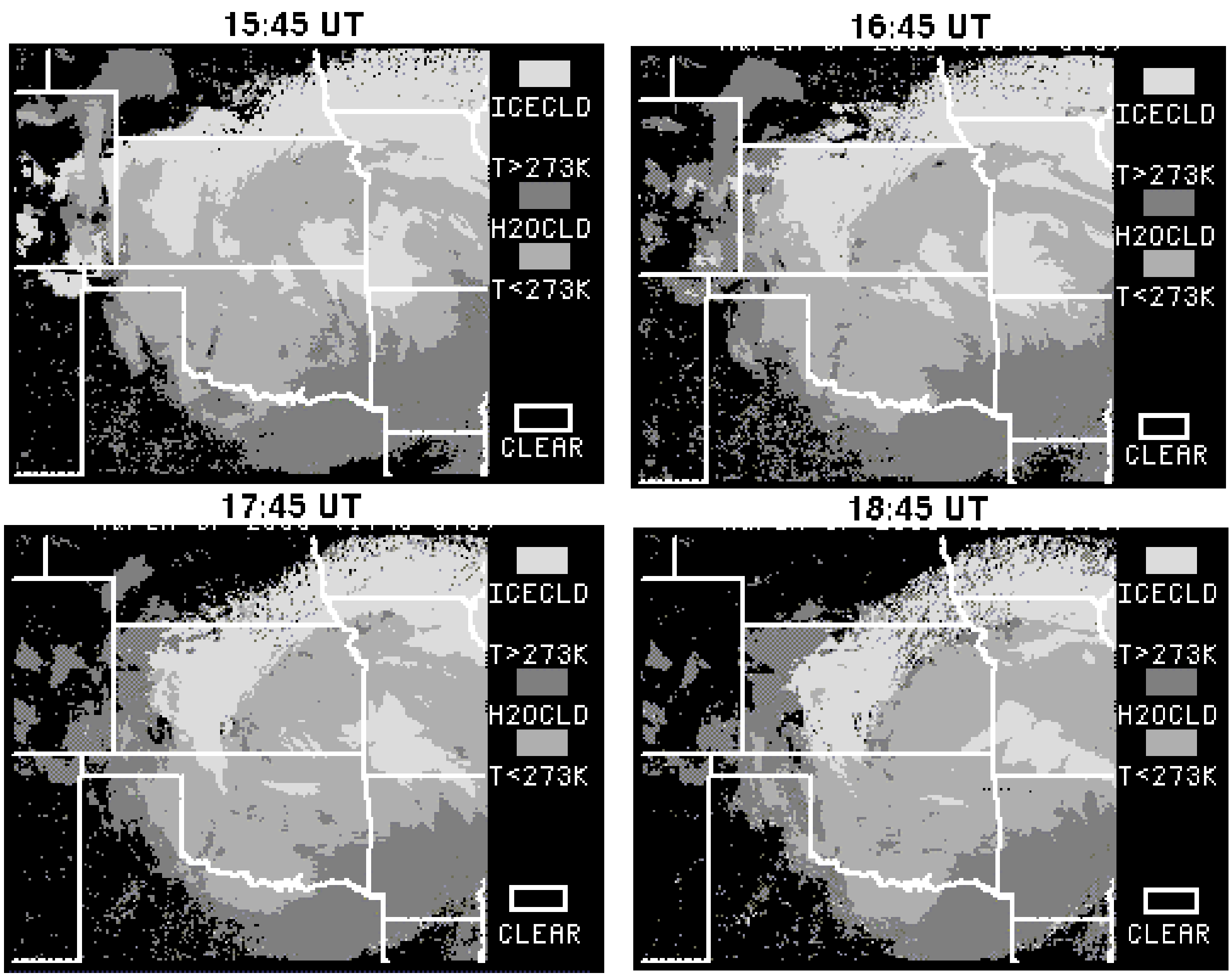

Figure 1. Cloud mask results for 15:45 UT – 18:45 UT on 3 March 2000 over the ARM SGP site. Clear areas are in black. The lightest shade of gray denotes ice clouds. Water clouds are the darkest gray. Supercoooled water clouds (T_{cloud}< 273 K) are an intermediate shade.

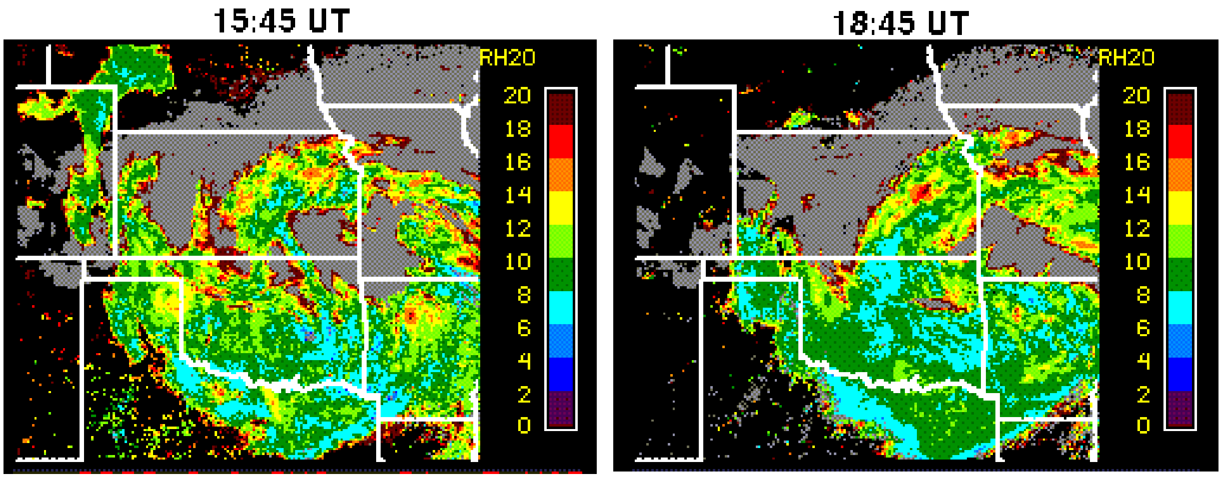

Figure 2. Retrieved water droplet size for 15:45 UT and 18:45 UT on 3 March 2000.

radiative properties derived over the ARM SGP site can be viewed at: *http://angler.larc.nasa.gov/armsgp/*.

The algorithm has also been used to produce cloud products for two additional field missions: the Interhemispheric differences in Cirrus Properties from Anthropogenic Emissions (INCA) 200 campaign off of southern Chile and the PanAmerican Climate Studies (PACS).

5. FUTURE WORK

Work has begun to incorporate additional channels in the cloud retrieval algorithms. Particle size retrieval algorithm using the 1.6 µm channel on VIRS in place of the 3.7 µm channel has been developed and tested over limited scenes. The arrival of MODIS data from Terra offers the opportunity to test nighttime algorithms that incorporate the 8.5-µm channel. Both of these channels have SEVERI counterparts on MSG.

The MSG data can be used to attack a wide variety of remote sensing problems \that could not be addressed with earlier instruments because of poor spectral, spatial, or temporal sampling. The combination of the algorithms described above with the additional channels from SEVERI will greatly enhance the quality of cloud products from geostationary satellites. We hope to process full disc SEVIRI and GERB data every 30 minutes for at least 1 year. Additional data may be needed for special case studies.

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